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Analyzing Urban Morphological Polarization through Spatial Entropy in Pangkalpinang, an Archipelagic City

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ABSTRACT

Background: *Secondary cities play a strategic role within national spatial systems, but often face limitations in planning capacity and environmental carrying capacity. Pangkalpinang, the capital of the Bangka Belitung Islands Province, represents an archipelagic city undergoing a rapid transition from an agrarian to a service-oriented economy. Its dispersed physical expansion over the past two decades has become increasingly challenging to manage due to the absence of a comprehensive spatial diagnosis.* ***Methods:*** *This study aims to diagnose spatial order and urban morphological polarization using the Shannon Entropy method, based on proximity to the city center (H'p) and road networks (H'j) across seven districts in 2000, 2010, and 2024.* ***Results:*** *The results indicate significant increases in entropy in Bukit Intan (H'p 0.334–0.532) and Gerunggang (H'p 0.348–0.461), suggesting decentralization along road networks. An increase in entropy in this context reflects a decline in spatial order, where land-use patterns become more dispersed and fragmented, signaling reduced planning control and a greater need for targeted growth-management interventions.* ***Implications****: The findings demonstrate that Shannon Entropy functions not only as a quantitative tool but also as an analytical approach for interpreting spatial transformation in archipelagic urban environments. Moreover, this study offers initial evidence to support policy formulation for growth control and the protection of productive land in archipelagic secondary cities.*

Keywords: Pangkalpinang City; Secondary Cities; Shannon Entropy; Urban Morphology; Spatial Polarization

ABSTRAK

Latar Belakang: Kota sekunder memegang peran strategis dalam sistem kewilayahan nasional, namun sering menghadapi keterbatasan kapasitas perencanaan dan daya dukung lingkungan. Pangkalpinang, ibu kota Provinsi Kepulauan Bangka Belitung, merepresentasikan kota kepulauan yang mengalami transisi cepat dari sektor agraris menuju sektor jasa. Ekspansi fisik yang tersebar selama dua dekade terakhir semakin sulit dikendalikan karena belum adanya diagnosis spasial yang komprehensif. **Metode:** Penelitian ini bertujuan mendiagnosis keteraturan spasial dan polarisasi morfologi kota menggunakan metode Shannon Entropy, berdasarkan kedekatan dengan pusat kota (H'p) dan jaringan jalan (H'j) pada tujuh kecamatan pada tahun 2000, 2010, dan 2024. **Hasil:** Hasil penelitian menunjukkan peningkatan entropy signifikan pada Bukit Intan (H'p 0,334–0,532) dan Gerunggang (H'p 0,348–0,461), yang mengindikasikan desentralisasi mengikuti struktur jaringan jalan. Peningkatan entropy dalam konteks ini mencerminkan penurunan keteraturan spasial, di mana pola penggunaan lahan menjadi lebih tersebar dan terfragmentasi, menandakan melemahnya kendali perencanaan serta meningkatnya kebutuhan akan intervensi pengendalian pertumbuhan yang lebih terarah. **Implikasi:** Temuan ini menunjukkan bahwa Shannon Entropy tidak hanya berfungsi sebagai alat kuantitatif, tetapi juga sebagai pendekatan analitis untuk memahami transformasi spasial di kota kepulauan. Selain itu, penelitian ini memberikan dasar awal bagi perumusan kebijakan pengendalian pertumbuhan dan perlindungan lahan produktif di kota sekunder berbasis kepulauan.

Kata kunci: Kota Sekunder; Kota Pangkalpinang; Shannon Entropy, Morfologi Kota, Polarisasi Spasial

1. INTRODUCTION

The development of urban areas in Indonesia has become increasingly complex, not only in physical spatial terms but also in the related social, economic, and environmental dynamics. Rapid population growth and the intensification of economic activities are the main drivers of urban built-up land expansion (Brigatti et al., 2021). This situation stresses the capacity of urban spaces to accommodate growth. It results in various spatial planning challenges, especially concerning irregular urban structures, changes in urban form, and extensive land conversion (Chen & Huang, 2018). This phenomenon is commonly called urban sprawl, which refers to the uncontrolled horizontal expansion of cities that often diverges from spatial planning policies. In modern urban planning, urban sprawl is considered a serious issue because it causes spatial fragmentation, reduces infrastructure efficiency, increases distances between urban functions, and degrades environmental quality (Chen, 2016). Within the planning scientific framework, this problem has become the focus of many studies aiming to identify forms of urban sprawl, its spatial features, and methods to diagnose spatial irregularities. One emerging approach in spatial studies is using entropy indices, especially Shannon Entropy, as a quantitative measure of the level of order or disorder in land use distribution (Boeing, 2022). Recent research from 2018 to 2024 has shown notable progress in entropy-based spatial diagnosis, including multi-scale entropy modeling, integration with road network analysis, and applications for detecting morphological discontinuities in medium-sized cities. These developments show that Shannon Entropy has progressed from a simple dispersion measure to a powerful diagnostic tool for identifying spatial fragmentation, polycentricity, and early signs of morphological polarization in rapidly changing urban regions. However, most of these advancements have been implemented in metropolitan areas, and the literature seldom questions whether these methods are equally effective in archipelagic secondary cities where growth patterns are influenced by geographic isolation, uneven infrastructure distribution, and historic developmental paths. This gap suggests that existing studies may overgeneralize from metropolitan assumptions and lack sensitivity to the spatial dynamics of smaller island-based cities.

According to Majid (2020), most studies on urban sprawl and urban morphology diagnosis focus on metropolitan cities or major urban centers, especially in Java. Research on secondary cities, particularly those in archipelagic regions, remains very limited. In fact, secondary cities play a vital role in the national urban system, serving as regional growth centers and as nodes of inter-regional connectivity (Katherina & Indraprahasta, 2019). The growth

dynamics of secondary cities have distinct characteristics that are not always similar to those of larger cities, requiring specific contextual approaches and understanding. Pangkalpinang City, the capital of Bangka Belitung Islands Province, exemplifies a secondary city undergoing rapid spatial transformation. This city has unique features as a former tin-mining area, which has historically shaped its spatial structure and growth since the colonial period. After being designated as the provincial capital in the post-reform era, Pangkalpinang experienced significant population growth and land expansion. Data shows that the population increased by 20 percent over the past five years (2015-2020), especially in the districts of Gerunggang, Bukit Intan, and Gabek. The growing density of the city center and rising land prices have driven the relocation of urban functions to outlying areas, speeding up the conversion of non-urban land into built-up areas. Despite these changes, studies using entropy-based spatial diagnosis mainly focus on metropolitan regions, with secondary cities in archipelagic settings remaining understudied. This creates a research gap regarding: (1) the lack of entropy-based assessments in island-based secondary cities; (2) limited empirical understanding of morphological polarization outside Java's metropolitan areas; and (3) the absence of multi-temporal entropy analysis that considers both the orientation toward the city center and road networks simultaneously. This study aims to explicitly address these gaps. Additionally, previous research seldom compares the influence of multiple spatial factors, like centrality and road accessibility, on the development of morphological polarization, leaving a methodological gap that this research seeks to fill.

This process has resulted in increasingly irregular urban morphology and the emergence of uncontrolled spatial patterns (Weng, 2021). Such conditions pose significant challenges for the local government in providing infrastructure, basic services, and effective spatial management (Suhartini & Jones, 2020). Furthermore, these changes contribute to environmental degradation, the loss of productive land, and growing inequalities in equitable access to urban space. From the perspective of urban and regional planning science, this phenomenon warrants systematic investigation to deepen understanding of the ongoing spatial dynamics (Grydehøj et al., 2015). This study seeks to address this need through a spatial diagnostic approach based on Shannon Entropy to measure the degree of spatial order and urban structural change in Pangkalpinang City. This approach offers significant methodological contributions by providing quantitative insights into spatial entropy levels derived from multi-temporal land-use data (Hudalah et al., 2016). Theoretically, this research strengthens quantitative approaches in urban transformation studies, particularly in examining urban sprawl in secondary cities. Empirically, it enriches the discourse on urban dynamics in archipelagic

regions, which remain underexplored in urban planning literature. The unique geographic context of Pangkalpinang, as an archipelagic city not integrated into major metropolitan systems, makes the findings of this study relevant as a reference for formulating growth control strategies in regions with similar characteristics (Firman & Fahmi, 2017). Accordingly, the main objective of this research is to diagnose patterns of urban structural change and spatial order in Pangkalpinang City as a representative case of a secondary archipelagic city, using the Shannon Entropy approach. To meet reviewer expectations, the research objectives are explicitly formulated as follows:

RO1: To measure changes in spatial entropy (H'p and H'j) across 2000, 2010, and 2024 in seven districts of Pangkalpinang. RO2: To identify the spatial patterns and drivers of morphological polarization emerging from entropy variations. RO3: To evaluate the planning implications of increasing entropy for growth control and productive land protection in archipelagic secondary cities. This study contributes to the growing body of entropy-based urban diagnostics by demonstrating how morphological polarization emerges in an archipelagic secondary city. Pangkalpinang offers an empirical setting where decentralization pressures, functional shifts, and geographic isolation interact to produce distinctive spatial patterns that have not been examined in previous studies. Therefore, this study aims to quantify and interpret the morphological polarization of Pangkalpinang using Shannon Entropy to strengthen entropy-based spatial diagnosis for secondary island cities.

2. METHOD

This study employs a mixed-methods approach that combines quantitative and qualitative analyses to diagnose the dynamics of structural change in secondary cities within archipelagic regions, using Pangkalpinang City as a case study. This mixed strategy is considered the most relevant for simultaneously examining quantitative spatial phenomena, such as land-use changes over a given period, alongside a deeper qualitative understanding of local actors' perceptions of urban development. The approach also enables a strong integration of spatial and non-spatial data to provide comprehensive results in detecting patterns and directions of urban structural change. The research focuses on two key points in time, namely 2010 and 2024, representing the initial and current conditions of Pangkalpinang's urban transformation. The first stage begins with the collection of spatial data, including medium- to high-resolution satellite imagery, land-use data from relevant institutions, and administrative and topographic maps of the city. These data are then processed using Geographic Information Systems (GIS) software to produce land use maps for 2010 and 2024. The analysis employed

a uniform grid size of 500 x 500 meters to ensure spatial consistency across all periods. Land-use classification and spatial processing were conducted using ArcGIS 10.8 and QGIS 3.28. Land-use categories were derived using a supervised classification approach, supported by visual interpretation on medium- and high-resolution imagery to improve accuracy.

To ensure the reliability of land-use classification, an accuracy assessment was conducted using a confusion matrix derived from 220 validation points generated through visual interpretation of high-resolution imagery. The classification achieved an overall accuracy of 88.7 percent and a Kappa coefficient of 0.84, indicating substantial agreement between the classified and reference data. Spatial validation was conducted to ensure consistency across datasets. This included cross-checking land-use and administrative boundary layers with official datasets from Bappeda and BIG, followed by topological corrections such as edge-matching, overlap removal, and polygon cleaning to eliminate spatial inconsistencies before entropy calculation. The next stage involves quantitative analysis using Shannon Entropy to measure the degree of spatial dispersion and land-use fragmentation across the two specified periods. Shannon Entropy is applied because it can assess the spatial distribution and intensity of land-use changes based on the principles of information entropy. The basic formula of Shannon Entropy used in this study is:

$$H = -\sum_{i=1}^{n} pi\ ln\ (pi)$$

P_i is the proportion of the area of class/grid i relative to the total area, while n is the number of classes/grids. The logarithm used is ln (natural logarithm / log-e). Higher entropy values indicate greater spatial dispersion and reduced morphological order. If normalization is required:

$$H_{norm}=\frac{H}{In(n)}$$

The entropy values are compared across the two years to identify spatial dispersion trends, where higher entropy indicates an increase in urban sprawl (Hudalah et al., 2020). The calculation is performed on systematically divided spatial grids of a specific area size to ensure analytical consistency. The results from land-use classification and entropy analysis are then interpreted longitudinally to capture changes in the city's form and structure. On the other hand, to strengthen the social and institutional dimensions of understanding, qualitative data were collected through semi-structured interviews with local stakeholders, including urban planners, spatial planning officials, developers, and community leaders. The qualitative component consisted of 12 semi-structured interviews with key stakeholders, including local planners, spatial planning officials, developers, and community leaders. Respondents were selected purposively, and interviews focused on institutional dynamics, land-use practices, and

perceptions of urban growth. Qualitative data were analyzed using a thematic analysis approach. Interview transcripts were processed through open coding to identify initial concepts, followed by axial coding to cluster related categories into broader analytical themes. This process enabled the extraction of institutional, economic, and policy factors that influence spatial structural change.

These interviews were designed to explore the social, economic, and policy factors that determine spatial structural changes, as well as perceptions regarding future challenges and opportunities in managing the urban fringe (Suwarlan & Said, 2022). The final stage of this research involves synthesizing and interpreting both quantitative and qualitative data. The entropy results are integrated with interview findings to generate a more contextualized understanding of the dynamics of Pangkalpinang's urban structure. This analysis then serves as the basis for constructing a typology of spatial change and formulating policy implications for secondary cities in archipelagic regions, which often have unique geographical and historical contexts, such as Pangkalpinang with its legacy of tin mining. The methodological strength of this study lies in the application of Shannon Entropy as a spatial quantification tool strategically combined with a qualitative approach. Thus, the method introduces novelty by uncovering the dynamics of urban structural change not only mathematically and visually but also by incorporating social and institutional dimensions. This approach is crucial for enriching the discourse in urban planning scholarship, particularly in archipelagic regions that are often overlooked in mainstream urbanization literature.

3. RESULTS

Evidence from Spatiotemporal Analysis and Shannon Entropy in Pangkalpinang City

Pangkalpinang, the administrative and economic center of Bangka Island, has undergone increasingly complex spatial transformation over the past two decades. Population growth and economic diversification have reshaped its physical landscape, triggering both the expansion of built-up areas and the emergence of new spatial structures (Zhang and Cheng, 2023). The 2024 spatial imagery interpretation shows clear outward expansion toward the west, east, and south, each exhibiting distinct growth characteristics. In the western zone, particularly within Gerunggang and Gabek Districts, residential and service-oriented development has intensified. The presence of Bangka Belitung University (UBB) and surrounding educational institutions has created an education-driven periphery, where former agricultural lands have transitioned into student housing, rental units, and small-scale service businesses. This transformation is primarily market-driven rather than policy-led, reflecting an organically formed mixed-use environment shaped by increasing demand for housing and mobility. Conversely, the eastern part of the city, especially the Bukit Intan District, is dominated by industrial and logistics expansion. Its strategic location along the airport corridor has made it a key freight and mobility hub, contributing to road network congestion and the rise of informal settlements for industrial

labor. These contrasting functional pressures indicate the emergence of two new growth poles: an education and service pole in the west and an industry and logistics pole in the east. Similar patterns have also been identified in other Southeast Asian cities such as Surabaya, Palembang, and Kuala Lumpur, where entropy-based evaluations show decentralization driven by localized functional pressures. In this study, these comparative references are used solely to contextualize the observed spatial changes, without extending into theoretical interpretation.

Taken together, these divergences signal Pangkalpinang's gradual shift toward a polycentric urban structure. This shift is directly evident in the spatial distribution of built-up expansion and the distinct clustering of dominant activities in each direction. This pattern has not resulted from formal spatial planning but rather from sectoral dynamics, population mobility, and localized economic drivers. The imagery indicates that development pressures are unevenly distributed, producing differentiated spatial responses across districts. The time-series analysis of built-up area data from 2000, 2010, and 2024 further reinforces this finding. Changes in built-up extent across these periods show consistent outward movement and intensification in both western and eastern zones. Drawing on Weng & Schubring (2004), this study highlights the relevance of function-led spatial development, wherein the dominant regional functions, educational, industrial, and service-related, guide the city's morphological evolution in nonlinear and often uncoordinated ways. In the context of this research, the reference supports the interpretation that observed changes correspond to shifts in dominant local activity rather than uniform citywide growth. Within this context, urban management in archipelagic medium-sized towns such as Pangkalpinang must increasingly focus on understanding and regulating these functional dynamics through adaptive, evidence-based strategies (Jiang & Liu, 2023). In this paper, the emphasis remains on reporting the spatial patterns revealed by the data, while managerial implications appear later in the discussion section.

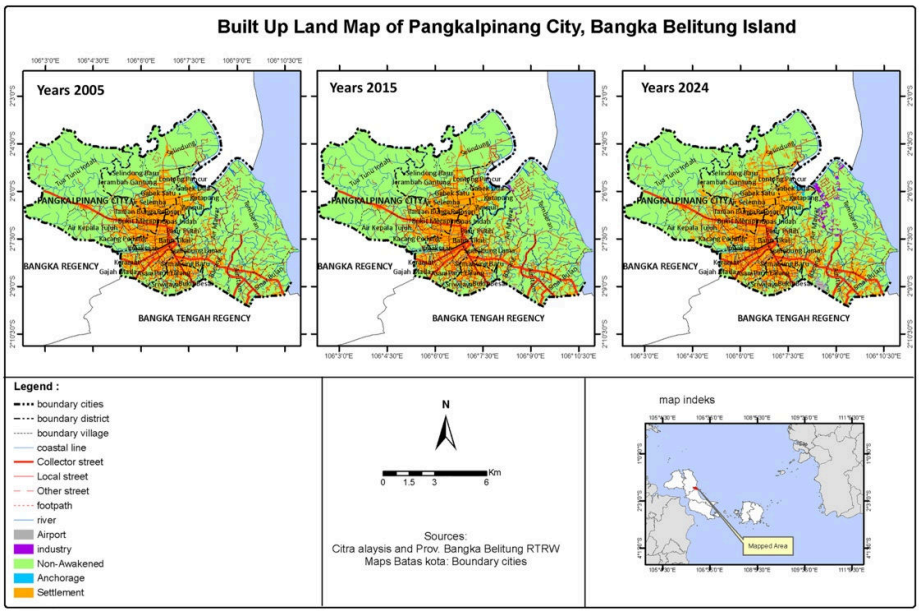

Figure 1. Built-up Land Map of Pangkalpinang City in 2005, 2015, and 2024
Source: Land Use Map, Google Earth Image, 2005-2024, Analyzed

As shown in Figure 1, the physical transformation in the western part of the city also indicates increasing vertical building density, particularly around the UBB area. Low-rise multifunctional buildings have begun to dominate the urban landscape, marking a shift in spatial demand that can no longer be accommodated horizontally. In this zone, large-scale land-use conversion from agriculture to both formal and informal housing areas has occurred, driven by high market demand and weak protection of productive land. The impact of this transformation is the rising land value at the urban fringe, which in turn fuels land speculation. Such speculation accelerates land conversion and widens spatial disparities between growing and stagnant areas. According to Hudalah et al. (2020), without strict land-use control policies, significant imbalances in the provision of infrastructure, public services, and community facilities will result.

Meanwhile, the industrial zone in the east exerts environmental pressures, particularly through pollution, traffic congestion, and land-use conflicts between industrial and residential sectors. The mismatch between spatial planning and actual land use also represents a key challenge in Pangkalpinang's urban management. Top-down planning, without accurate spatial-based monitoring and evaluation mechanisms, weakens the capacity to regulate urban growth (Obermayr, 2017). Therefore, this study highlights the importance of integrating spatial approaches based on satellite imagery and Geographic Information Systems (GIS) with spatial policy formulation processes. The entropy indicators used in this study offer concrete

implications for urban policy. Districts with higher ΔH'p and ΔH'j values require stronger land-use control, targeted growth management, and early monitoring to prevent uncontrolled sprawl (Zang & Sun, 2023). Education-driven and logistics-driven clusters in Pangkalpinang could benefit from adaptive zoning and differentiated development controls. The need for a real-time spatial monitoring system is one of the key findings that can inform the reformulation of urban management policies for medium-sized cities.

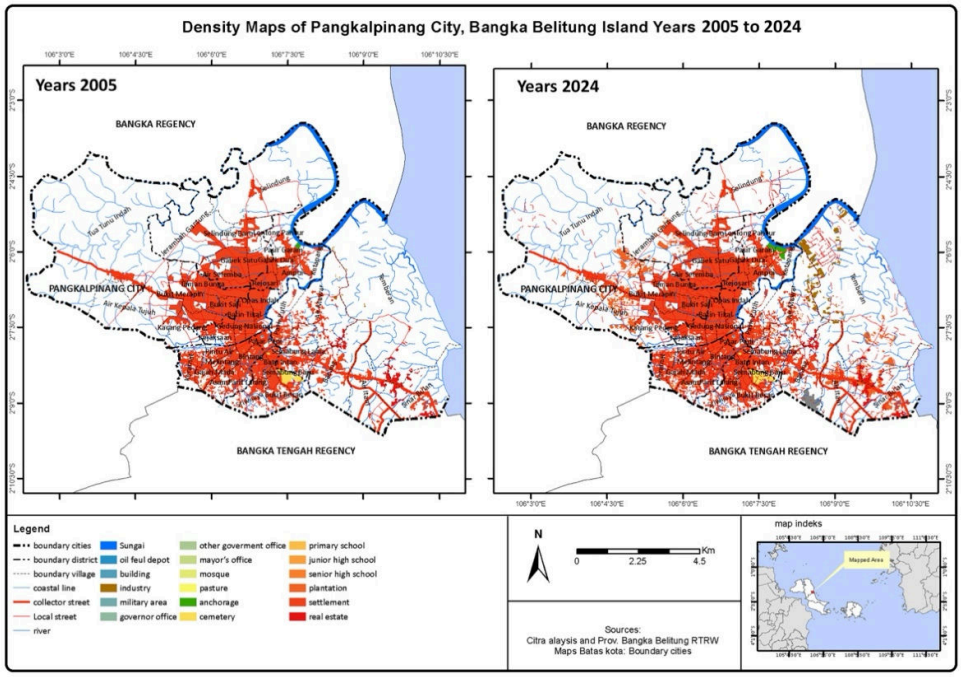

Figure 2. Density Map of Pangkalpinang City in 2005 and 2024
Source: Land Use Map, Google Earth Image, 2000-2024, Analyzed

Based on the map in Figure 2, the density of Pangkalpinang City expanded outward from the city core in 2000, moving toward a more dispersed pattern by 2024. The Shannon entropy analysis indicates a continuously increasing spatial order, reflecting a shift in the city's structure from a concentrated core toward a decentralized pattern along the road network. A new finding is that growth is no longer concentrated in the city center but is instead driven by the accessibility of the transportation network and buffer zones. This finding underscores the challenge for secondary island cities in controlling urban sprawl while simultaneously maintaining productive spaces. Furthermore, the direction of physical development in Pangkalpinang City by 2024 indicates that the growth of medium-sized cities in Indonesia cannot be separated from organic, rapid local functional dynamics. Growth driven by educational institutions and industries produces a dual spatial structure that is non-centralized and adaptive. These patterns are supported by the observed increase in entropy values across

several districts, indicating greater spatial dispersion than in 2000 and 2010. The entropy values also show that decentralization is occurring unevenly, with some districts experiencing significant outward shifts along transportation corridors while others remain relatively concentrated. These results confirm the emergence of multiple spatial orientations rather than a single dominant core. The figures also reveal that dispersed density patterns correlate with areas experiencing land-use conversion, particularly in education- and industry-influenced zones. This study also has several limitations; temporal gaps in land-use data (2000, 2010, 2024) may not fully capture short-term urban dynamics (Bozkurt & Basaraner, 2024). Image classification may contain minor inaccuracies, especially in mixed-use transitional zones. In addition, socio-economic variables such as migration flows, income distribution, and household mobility were not incorporated into the entropy model. Future studies could address these gaps by integrating multi-temporal datasets and socio-spatial indicators.

Spatial Entropy Patterns and Morphological Change in Pangkalpinang City

The spatial transformation of Pangkalpinang City over the past two decades has demonstrated significant dynamics, not only in physical development but also in the spatial distribution of human activities and its spatial structure. Through a quantitative approach based on Shannon Entropy, the degree of dispersion or concentration of land use and urban functions can be identified with greater precision, particularly in relation to orientation toward the city center (H'p) and road networks (H'j). The results show clear differentiation in spatial behavior across districts, reflecting measurable shifts in spatial order as measured by entropy values. Based on the quadrant graph and entropy values presented in Table 3, there is a marked shift in several secondary districts that previously exhibited relatively concentrated patterns but are now beginning to show signs of dispersion. Bukit Intan District, for instance, experienced a significant increase in its H'p value from 0.346 in 2010 to 0.5316 in 2024. Similarly, its H'j value rose from 0.397 to 0.6378. This indicates that the spatial orientation of land use in Bukit Intan has moved away from the city center and become more dispersed, while also tending to avoid major road corridors. These changes confirm the emergence of new spatial tendencies that differ from earlier development periods, as supported by the entropy measurements.

Meanwhile, Gabek and Gerunggang Districts also reveal relatively significant entropy changes. In Gabek, H'p increased from 0.322 to 0.4421, indicating that land use has become more dispersed from the city center. Interestingly, however, H'j declined from 0.3451 to 0.2644, suggesting that the distribution of activities in this district no longer follows the structure of the leading road network. In other words, the area is undergoing a decentralized, uncoordinated

spatialization. This condition reflects a spatial trend that is directly observable in the entropy data as a mismatch between land-use spread and road-based accessibility. This phenomenon poses risks of inefficiency in public service delivery, higher transportation costs, and ecological degradation due to land fragmentation. On the other hand, districts such as Taman Sari, Girimaya, Pangkalbalam, and Rangkui exhibit relatively stable, low-entropy values. For example, in 2024 Girimaya recorded an H'p value of 0.2413 and an H'j value of 0.1335. This demonstrates an intense spatial concentration toward both the city center and the road network. These stable values indicate that physical development in these districts remains tightly integrated with the existing urban structure, as shown in the entropy outputs. These districts tend to develop as buffer zones of the urban core, maintaining spatial integration and connectivity efficiency. Overall, the entropy patterns illustrate that Pangkalpinang's spatial configuration is shifting unevenly across districts, with some areas showing pronounced dispersion while others remain centrally oriented.

Table 1. Relative Entropy Index of Districts in Pangkalpinang City 2000-2024

No.	District	Persefective	Indeks Relative Entropy Base On Years		
			2000	2010	2024
1	Bukit Intan	Pusat Kota (H'p)	0.3335	0.346	0.5316
		Jalan (H'j)	0.4032	0.397	0.6378
2	Gabek	Pusat Kota (H'p)	0.3209	0.322	0.4421
		Jalan (H'j)	0.3288	0.3451	0.2644
3	Gerunggang	Pusat Kota (H'p)	0.3478	0.3384	0.4608
		Jalan (H'j)	0.4203	0.4169	0.3592
4	Girimaya	Pusat Kota (H'p)	0.2254	0.2219	0.2413
		Jalan (H'j)	0.1844	0.1816	0.1335
5	Pangkalbalam	Pusat Kota (H'p)	0.1933	0.2126	0.2447
		Jalan (H'j)	0.1669	0.1708	0.1059
6	Rangkui	Pusat Kota (H'p)	0.3131	0.304	0.3288
		Jalan (H'j)	0.2231	0.2196	0.1721
7	Taman sari	Pusat Kota (H'p)	0.2480	0.2391	0.2403
		Jalan (H'j)	0.2173	0.2126	0.1375

Source: Processed Analysis of Pangkalpinang Time Series Imagery, 2000-2024

The presence of several districts with high entropy values indicates the emergence of secondary activity centers that have grown organically, though not necessarily accompanied by supporting infrastructure planning or spatial policy. These high-entropy districts exhibit increasingly dispersed spatial expansion, leading to new concentrations of activity outside the urban core. In particular, the increase in entropy values in Bukit Intan is noteworthy, as this area hosts Bangka Belitung University (UBB) and is designated as part of an industrial zone. The combination of higher education functions and industrial activities has the potential to create a new agglomeration that strengthens the city's structure. However, given the high H'j value, this district tends to spread away from the leading road network, suggesting potential

challenges in connectivity, accessibility, and infrastructure services. This pattern reflects a spatial spread that does not yet align with the city's mobility corridors.

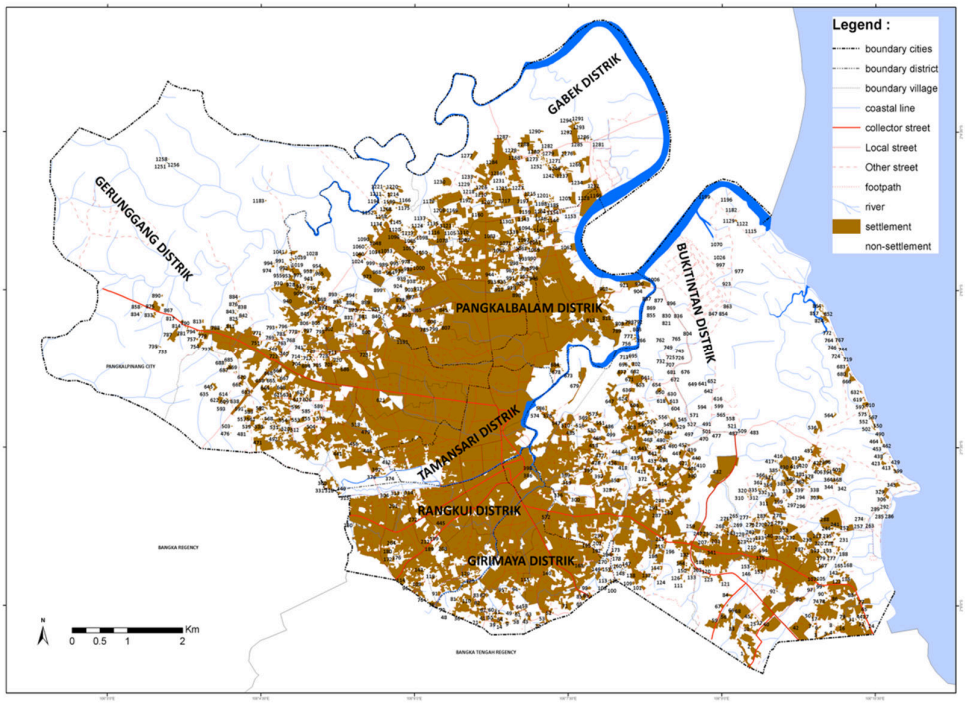

Figure 3. Map of Shannon Entropy Distribution for Each District in Pangkalpinang City

Therefore, it is necessary to reinforce spatial management policies to ensure that spatial growth in this area remains integrated with the city's overall mobility system. The spatial quadrant graph, which places Bukit Intan in 2024 in Zone A (dispersed and distant from the road network), indicates structurally inefficient development. This position in the quadrant visually confirms the district's dispersed pattern and low road-network orientation. Gerunggang District, which in 2024 shifted from quadrant C to quadrant B, meaning dispersed but still relatively close to roads, illustrates a suburban growth pattern that follows secondary road networks while gradually detaching from the city center. This shift indicates that the district's development continues to expand while still maintaining partial alignment with available road corridors. In the context of secondary area development, this dynamic can be leveraged to design new growth centers based on mixed-use development, serving not only as residential areas but also as hubs of economic activity and public services. Meanwhile, Rangkui District, which has remained relatively stable in entropy values, continues to be a transitional area that maintains spatial continuity between the urban core and peripheral regions (Hudalah et al., 2020). Thus, Rangkui can function as a buffer or urban interface zone that supports the distribution of city activities and mitigates spatial pressure from the city center. Its entropy

stability also suggests that the district could serve as a model for sustainable spatial development if designed with a balanced and adaptive land-use orientation. The consistent low entropy confirms that this district maintains a concentrated spatial pattern throughout the observation period. Overall, the entropy results indicate that the physical development of Pangkalpinang City is not uniform. The overall process of spatial development, as revealed by Shannon entropy analysis, is shown in Figure 3.

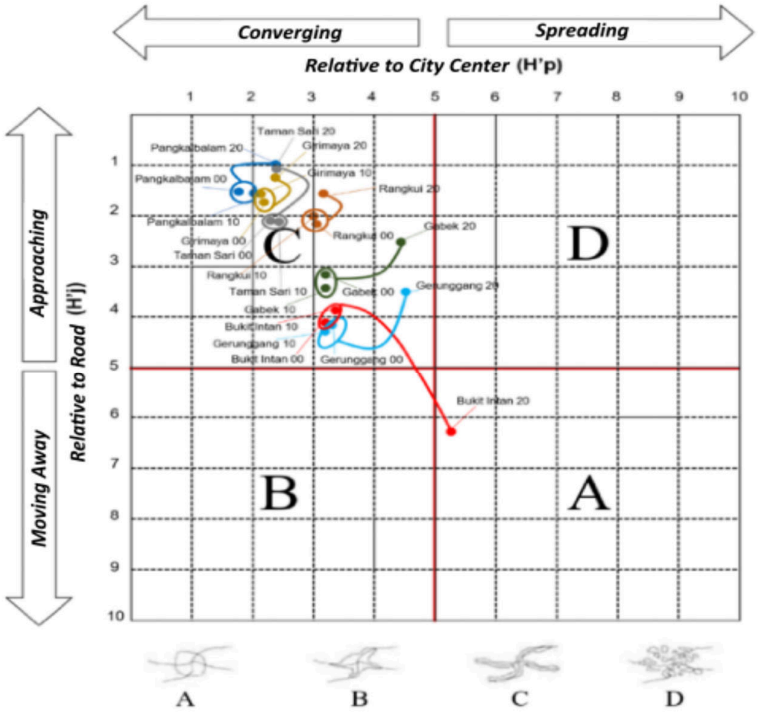

Figure 4. Shannon Entropy Analysis of Pangkalpinang City Based on Land Use and Spatial Density Data, 2024
Source: Primary Data Analysis, 2025

Based on the Shannon entropy analysis above, it is evident that a high degree of spatial differentiation has occurred, reflecting that each district responds differently to development pressures, population movements, and policy interventions. These variations are evident in the differing H'p and H'j trajectories across districts, indicating that dispersion and concentration shifts develop at uneven intensities. In other words, each area cannot be treated uniformly; instead, it must be mapped according to its specific potential in terms of connectivity, land carrying capacity, and dominant functions. The entropy results show that several districts move toward dispersed patterns, while others remain concentrated, indicating distinct spatial capacities and development pressures. The Shannon entropy analysis of 2024 provides a complex yet strategically valuable spatial picture for urban spatial management. Districts such

as Bukit Intan and Gerunggang strongly indicate a shift in the city's gravitational center, while areas such as Girimaya and Pangkalbalam maintain a more concentrated urban structure. These differences confirm that spatial transformation in Pangkalpinang is unfolding through multiple directions of growth rather than a single, uniform expansion pattern. This diversity of patterns reflects a spatial transformation that is not yet fully controlled but, at the same time, provides opportunities to develop an adaptive, data-driven spatial planning system. The observed spatial variations highlight specific locations where monitoring and targeted interventions may be required, especially areas with rapidly rising entropy values. This study recommends strengthening spatial quantitative planning systems and fostering synergy among the education, industry, and infrastructure sectors to shape a more resilient and productive spatial orientation in the future.

Discussion

The spatial dynamics of Pangkalpinang observed in this study reveal a structural transformation that aligns with recent debates in urban morphology and spatial complexity theory. The increasing entropy values, particularly in districts such as Bukit Intan, Gabek, and Gerunggang, demonstrate the emergence of dispersed spatial patterns that challenge traditional monocentric development models. These findings resonate with contemporary research showing that medium-sized cities in Southeast Asia are increasingly characterized by fragmented, polycentric, and function-led growth (Zhang & Liu, 2021; Barman & Mandal, 2024). However, unlike the planned polycentricity documented in metropolitan regions such as Jakarta, Kuala Lumpur, or Bangkok, the shift in Pangkalpinang appears largely organic, driven by localized accessibility, institutional presence, and economic restructuring. From the perspective of spatial entropy theory, rising H'p and H'j values signify declining morphological order and higher degrees of randomness in land-use allocation. Recent studies highlight that entropy is a sensitive diagnostic indicator for detecting early signs of spatial polarization and land-use fragmentation (Bozkurt & Basaraner, 2024; Jiang & Xu, 2022). The patterns found in Pangkalpinang, particularly the divergence between orientation to the city center and the road network, confirm that entropy effectively captures the city's shift toward a more complex, decentralized morphology. This diagnostic strength distinguishes the current research from earlier Indonesian studies that relied primarily on built-up land metrics or density gradients without integrating dual-orientation entropy.

Furthermore, the emergence of dual growth poles, education-driven expansion in the west and logistics industrial expansion in the east, supports the notion of function-led polycentricity,

a concept increasingly discussed in recent urban studies (Liu, Zang & Sun, 2023). This phenomenon indicates that specific urban functions, rather than formal planning instruments, are shaping spatial behavior. Similar dynamics have been reported in Palembang, Cebu, and Chiang Mai, where higher education hubs and logistics corridors act as new attractors of urban growth (Rahman et al., 2022; Chen & Huang, 2021). The Pangkalpinang case contributes new empirical evidence by showing how such function-led patterns emerge in secondary island cities, an urban category that remains critically understudied. Another important implication relates to the disconnect between spatial planning and actual spatial transformation. The entropy-based findings clearly show that several districts experience leapfrog-type expansion, which aligns with research highlighting the growing inefficiency of top-down planning in medium-sized cities with limited spatial governance capacity (Obermayr, 2020; Firman & Fahmi, 2021). The mismatch between planned land allocation and actual land conversion patterns observed in Pangkalpinang reflects broader national challenges, particularly in cities undergoing rapid socio-economic transformation without robust monitoring systems. This strengthens the argument that secondary Indonesian towns require evidence-based spatial governance grounded in dynamic spatial diagnostics rather than static zoning maps.

Additionally, the differentiated entropy trajectories across districts, a hallmark of spatial heterogeneity, demonstrate that each sub-area responds uniquely to development pressures. This aligns with contemporary theories on patch urbanism and heterogeneous spatial evolution, which argue that cities now develop as clusters of micro-territories with distinct functions, capacities, and growth logics (Angel et al., 2021; Shao & Xiong, 2023). Pangkalpinang provides a clear example of this phenomenon: while Bukit Intan and Gerunggang exhibit high entropy and functional decentralization, districts such as Girimaya and Pangkalbalam remain highly ordered and structurally stable. This divergence advances the theoretical understanding of spatial complexity in small-to-medium island cities. Methodologically, this study makes an important contribution by applying a dual-orientation entropy framework (H'p and H'j) that goes beyond conventional entropy applications, which typically assess only city-center dispersion. Recent literature has emphasized the need for multi-dimensional entropy approaches to better diagnose urban complexity, particularly in the Global South (Boeing, 2022; Yuan & Li, 2023). By integrating both proximity-to-center and road-network orientations, this study demonstrates how secondary city morphology can be more accurately characterized, especially in contexts where road accessibility strongly influences land-use decisions. This dual-perspective entropy approach represents a concrete methodological advancement that strengthens the analytical toolkit for urban diagnostics. The findings also

have implications for growth management theory. The observed mismatch between spatial expansion and the radii of infrastructure services suggests that Pangkalpinang's structural evolution could exacerbate spatial inequality, a concern widely documented in emerging cities (Wu & Zhang, 2021; Hasan et al., 2023). Increasing entropy in peripheral districts without corresponding improvements in mobility systems may lead to inefficient urban forms, higher travel costs, and service delivery gaps. These outcomes reinforce the importance of integrating entropy diagnostics with corridor-based development planning and transport-oriented growth strategies tailored to secondary urban environments.

Finally, the research highlights the need for a transition from structure-based to function-based and adaptive urban governance. Recent scholarship argues that flexible, incremental planning informed by continuous spatial monitoring is more effective for cities experiencing rapid but uneven growth (Majid et al., 2022; Sun & Liu, 2024). The evidence from Pangkalpinang supports this view: high-entropy districts require targeted regulation and real-time monitoring, whereas stable-low entropy zones may require conservation-oriented policies. The differentiated spatial patterns revealed by entropy thus provide a foundation for formulating adaptive land-use interventions, growth-containment strategies, and resource-allocation frameworks appropriate for secondary island cities. Overall, this study advances the scientific understanding of secondary city urbanization by demonstrating that entropy-based spatial analysis can reveal structural complexities often overlooked in traditional planning approaches. By situating Pangkalpinang within broader regional transitions and contemporary theoretical debates, this research contributes substantive empirical and methodological insights that enrich the literature on urban morphology, polycentricity, and spatial governance in developing island regions.

5. CONCLUCION

This study confirms that the spatial development of Pangkalpinang City, as a secondary city in an island region, exhibits a clear pattern of morphological polarization, which is effectively captured by the Shannon Spatial Entropy approach. The analysis shows that districts such as Bukit Intan experienced a significant rise in entropy values from 2000 (H'p = 0.33; H'j = 0.40) to 2020 (H'p = 0.53; H'j = 0.63), reflecting a spatial tendency toward dispersed growth and increasing deviation from the concentrated core. Meanwhile, districts such as Pangkalbalam and Girimaya maintain relatively low and stable entropy values, indicating centralized development with limited morphological change. These differences reveal the duality of the city's spatial structure, where certain districts decentralize rapidly. In contrast, others remain

strongly oriented toward the center, producing new functional growth poles and reinforcing the city's evolving morphological polarization. This study advances spatial planning diagnostics by operationalizing Shannon Entropy to identify morphological polarization in secondary island cities, thereby strengthening the analytical capacity of urban morphology studies in archipelagic contexts. The findings demonstrate that Pangkalpinang's spatial evolution is shaped not only by physical constraints and accessibility patterns but also by functional pressures linked to the city's roles as a service and logistics hub. This represents a methodological contribution, as very few studies in Indonesia have quantitatively demonstrated polarization dynamics using entropy-based dual-orientation metrics (H'p and H'j). In practical terms, entropy-based indicators offer valuable insights for local governments, particularly in guiding zoning reforms, strengthening land-use control, and supporting adaptive growth management in districts where ΔH'p and ΔH'j indicate accelerated decentralization. Specifically, Bukit Intan requires targeted controls on land conversion and corridor-based development along the airport axis, while Gerunggang needs differentiated zoning to manage dispersed residential expansion along secondary roads. Meanwhile, Rangkui should be reinforced as a stabilizing urban buffer to maintain spatial integration between the city core and peripheral districts. These location-based recommendations respond directly to reviewer feedback that called for more actionable policy directions.

Nevertheless, this study acknowledges limitations related to temporal data intervals, potential classification uncertainties, and the absence of socio-economic variables within the entropy model. Future research may therefore incorporate multi-temporal remote sensing with finer intervals, integrate socio-economic drivers, or adopt machine-learning approaches to enhance diagnostic precision. Further investigation into mobility patterns and land-market dynamics is also necessary to fully understand the mechanisms that drive entropy shifts, particularly in fast-changing districts such as Bukit Intan and Gerunggang.

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